Physics 102 Lab 2: Mapping the electric field of a dipole

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Theoretical Discussion

Electric Forces and Fields: The electric force between two point charges q_1 and q_2, located a distance r apart, is equal to

$$\vec{F}(q_1, q_2, \vec{r}) = \frac{kq_1q_2}{r^2}\,\hat{r}$$

where the charges q_1 and q_2 are in Coulombs, r is the distance in meters between the charges and

$$k = 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$$

is a constant that reflects the inherent strength of the electric field. The direction of the force lies along the line connecting q_1 and q_2, and is repulsive if both charges have the same sign and attractive if the charges have opposite signs.

We can, if we wish, make an arbitrary distinction between q_s, which we will call the *source charge* and q_t, which we call the *test charge*, and suppose that the source charge creates an *electric field* which will exert a force on any test charge q_t we place within it.

The electric field $\vec{E}$ due to a source charge q_s, at a field point located a distance r away from q_s, is

$$\vec{E}(q_s, \vec{r}) = \frac{kq_s}{r^2}\,\hat{r}$$

so that $\vec{F}(q_s, q_t, \vec{r}) = q_t\vec{E}(q_s, \vec{r})$ and likewise, $\vec{E}(q_s, \vec{r}) = \frac{1}{q_t}\vec{F}(q_s, q_t, \vec{r})$

The electric field due to a collection of source charges $\{q_j\} = \{q_1, q_2, \ldots, q_n\}$ is the vector sum of the fields due to each of them individually, so that

$$\vec{E}(\{q_j\}, \vec{r}) = \sum_{i=1}^{n} \vec{E}(q_i, \vec{r}) = \vec{E}(q_1, \vec{r}) + \vec{E}(q_2, \vec{r}) + \cdots \vec{E}(q_n, \vec{r})$$

A test charge q_t placed in this field at the field point $\vec{r}$ will experience a force $\vec{F}(\{q_j\}, q_t, \vec{r}) = q_t\vec{E}(\{q_j\}\vec{r})$.

In this experiment, a pair of electrodes are placed in a bath of salt water. The source charges on the electrodes create an electric field. Salt water is a good conductor, which means that it has a relatively large number of mobile charge carriers. These charge carriers play the role of test charges. They will experience a force due to the field created by the electrodes and will be accelerated. The moving test charges constitute a *current*, which flows in the direction of the electric field.

The (immobile) charges on the electrodes create an electric field, which causes the (mobile) charges in the saltwater to accelerate, thereby creating a current in the saltwater.

Electric Potential Energy and Electric Potentials: When a force accelerates a particle through some distance, it does work on the particle, changing its potential energy U. If a charged particle is displaced through a small distance $\Delta\vec{s}$ under the influence of the force $\vec{F}$, the change in its potential energy, ΔU, is given by

$$\Delta U = -\vec{F} \cdot \Delta \vec{s}$$

If the force and the displacement are perpendicular to one another, then according to the definition of the dot product, the change in potential energy is zero; i.e.,

$$\text{If } \vec{F} \perp \Delta \vec{s}, \text{ then } \Delta U = 0 \qquad (1)$$

A very important consequence of this equation is that *the potential energy of a particle does not change as you move it along a curve which is perpendicular to the direction of the force.* This is true of *all* forces, not merely electric forces.

Just as the electric field is the force per unit test charge due to a configuration of source charges, the *electric potential* V is the electric potential energy per unit test charge due to the source charge configuration. Since $\vec{E} = \frac{1}{q_t}\vec{F}$ and $V = \frac{1}{q_t}U$, dividing both sides of equation 1 by the test charge q_t gives the relation between the change in electric potential ΔV between two points in an electric field $\vec{E}$ connected by a displacement vector $\Delta \vec{s}$:

$$\Delta V = -\vec{E} \cdot \Delta \vec{s}$$

It follows that the potential doesn't change along a curve perpendicular to the direction of the electric field. The curves along which the electric potential V is constant are called *equipotential lines.*

Current flows in the direction of the electric field. Equipotential lines are everywhere perpendicular to this direction and no current flows along them.

Experimental Procedure

Synopsis

- We set up an electric field in a bath of salt water by placing positive and negative electrodes in it.
- We map the equipotential lines by finding curves along which no current flows.
- We map the electric field by drawing lines connecting the electrodes that intersect the equipotential lines at right angles.

Detailed Instructions (see figure 1)

1. Make sure that your pan contains a plotting sheet. Cover the sheet with a thin layer of saltwater.
2. Place the (+) and (−) electrodes on the circles on your plotting sheet. Your instructor will check the circuit before turning up the voltage.
3. Place the stationary probe at the first of the square stationary probe marks. An electric circuit connects this probe through a galvanometer (current meter) and a moveable probe. When current flows through this circuit, the galvanometer will register it; as the current goes to zero, the galvanometer reading will go to zero also. By searching with the moveable probe for points of zero current, and marking them on the plotting sheet, you can map out an equipotential line.
4. As you locate each point of zero current in your pan, mark this location on your individual sheet of graph paper.
5. Repeat this procedure for each of the stationary probe locations. This will give you a family of equipotential lines.
6. Map the electric field lines as follows:

- Your first field line will be the straight line connecting the electrodes.
- Sketch additional lines by
  - estimating the points at which a particular line will cross the equipotential curves at right angles (90°), and connecting these points.
- Sketch at least 6 field lines symmetrically about the central line (three above and three below).

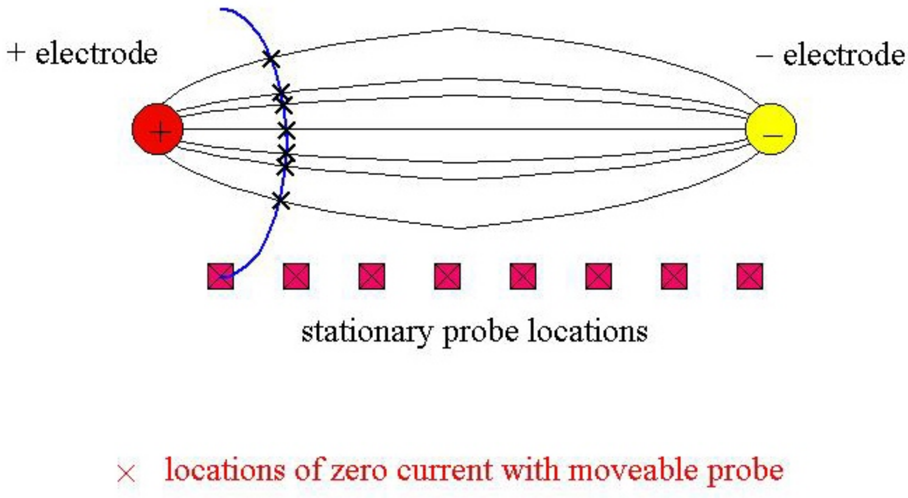

FIG. 1: Illustration of the experimental setup and procedure